

**DJpsiFDC:**  
**an event generator for the process  $gg \rightarrow J/\psi J/\psi$  at LHC**

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**Abstract**

DJpsiFDC is an event generator package for the process  $gg \rightarrow J/\psi J/\psi$ . It generates events for primary leading-order  $2 \rightarrow 2$  processes. The package could generate a LHE document and this document could easily be embedded into detector simulation software frameworks. The package is produced in Fortran codes.

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**Keywords:** Event generator, FDC,  $J/\psi$  pair, color-octet scheme

**Program summary**

*Program Title:* DJpsiFDC

*Operating system:* Linux (with GNU FORTRAN 77 compiler)

*Programming language:* FORTRAN 77

*External libraries:* CERNLIB 2001 (or CERNLIB 2003)

*Distribution format:* tar gzip file

*Size of the compressed file:* 2.99M Bytes.

*Classification:* 11.1

## I. INTRODUCTION

NRQCD[1] has now become a basic theory to parameterize non-perturbative contributions represented by color-singlet(CS) and color-octet(CO) matrix elements in heavy quarkonium production and decays . The color-octet mechanism supplies a way to partly understand the prompt  $J/\psi$  and  $\psi'$  surplus production at the Fermilab Tevatron [2, 3]. However, there are still something unclear in this scheme[4–11]. To investigate charmonium production mechanism has become an urgent and important task in the study of quarkonium physics.

$J/\psi$  pair production process could be a candidate for testing and verifying color-octet scheme. This process has an exclusive multi-muon final state with extremely small backgrounds. But according to the result of previous unpolarized calculations[12, 13] for Tevatron experiment, the cross-section of this process at Tevatron is very small, and Tevatron experiment also has not supplied a solid evidence for having detected it.

The running of the LHC provides a great opportunity to realize this aim. With high center-of-mass energy of 14 TeV and luminosity of about  $10^{32} \sim 10^{34} cm^{-2}s^{-1}$ , results from the LHC experiment may be able to answer how much color-octet mechanism contributes to  $J/\psi$  production under high collision energy. With regard to the calculations of Qiao *et al* [14] and Li *et al* [15], the  $J/\psi$  pair production process at LHC could study charmonium production mechanisms. But firstly, we must perform Monte Carlo simulation on this process to research its experimental feasibility. Thus, we developed a generator package on this process based on Feynman Diagram Calculation (FDC) system[16]. The generator contains only primary leading order  $gg \rightarrow J/\psi J/\psi$  channels, and we neglected those channels such as  $q\bar{q} \rightarrow J/\psi J/\psi$  which contribute much less to than  $gg \rightarrow J/\psi J/\psi$  processes. The output of the generator is a standard Les Houches Event file[17], and could be embedded to the detector simulation software framework.

The transverse momentum (Pt) distributions of muons from  $J/\psi$  generated in color-singlet and color-octet schemes are shown here. In large Pt region (Pt > 10 GeV), the muons from  $J/\psi$  generated in color-octet scheme are more than those from  $J/\psi$  generated in color-singlet scheme. That means significant more  $J/\psi$  in color-octet scheme could be reconstructed in large Pt region. If more  $J/\psi$  events were detected in large Pt region, then it could be considered that color-octet scheme contributes significantly to the cross-section

of the process. If the cross-section was measured, the contribution of color-octet scheme could also be determined.

This paper is organized as follows: In Section 2, the directory structures of the event generator package are described. In Section 3, we describe the details of the installation and implementation of DJpsiFDC package. Sections 4 describes the format of the output files. The summary is presented in Section 5.

## II. DIRECTORY STRUCTURES

There are five sub-directories in the directory. They are `basesv5.1`, `DJpsi-generator`, `f77`, `gg2jpsi` and `octet_gg2jpsi`. The directory `basev5.1` stores BASES libraries used for Monte-Carlo calculation of the cross-section integral. The directory `f77` are the common-shared computational tools for physics quantities, such as  $\alpha_s$ , etc, and the directory `DJpsi-generator` contains the  $J/\psi$  pair production information.

`gg2jpsi` and `octet_gg2jpsi` are two directories containing color-singlet and color-octet parts of  $J/\psi$  pair production process respectively. All the compiled executable programs

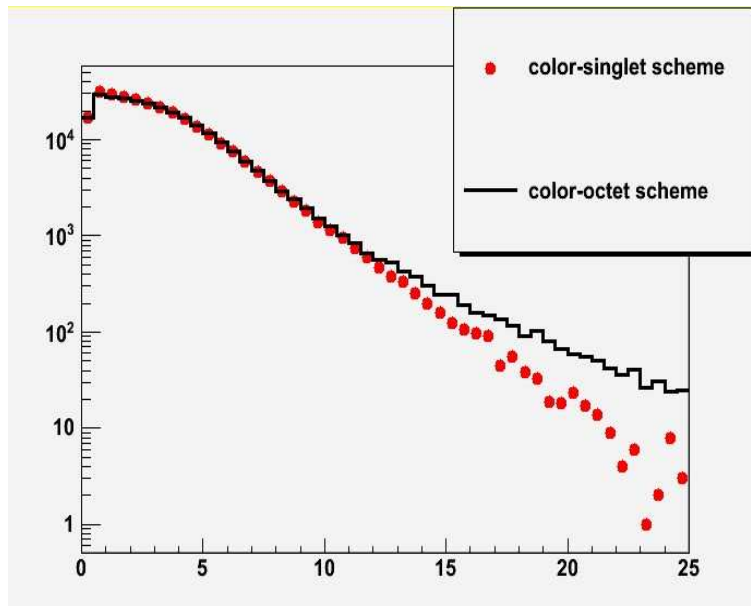


FIG. 1: Transverse momentum distribution of muon from  $J/\psi$  in color-singlet and color-octet schemes generated by DJpsiFDC package.

and the input files are stored in these two directories. In the following, the two parts would be described sequentially.

### A. Color-Singlet Scheme

In color-singlet part, we restrict simulation objects merely to the gluon-gluon fusion one, as shown in Figure ?? . In fact,  $J/\psi$  pair production process in color-singlet scheme includes  $g + g \rightarrow J/\psi + J/\psi$  and  $q + \bar{q} \rightarrow J/\psi + J/\psi$ . Since  $q + \bar{q} \rightarrow J/\psi + J/\psi$  processes contribute much less, we did not consider this part's contribution.

### B. Color-Octet Scheme

In the color-octet scheme, the final objects produced in hard parton interaction are not  $J/\psi$ s, but color-octet bound states, as shown in Figure ?? . Here we comply with the convention in PYTHIA system, considering this color-octet bound state as a new particle, and assuming its invariant mass is 30MeV larger than  $J/\psi$ , which is 3.126GeV. The color-octet bound state would radiate a soft gluon, and decay to a real  $J/\psi$ .

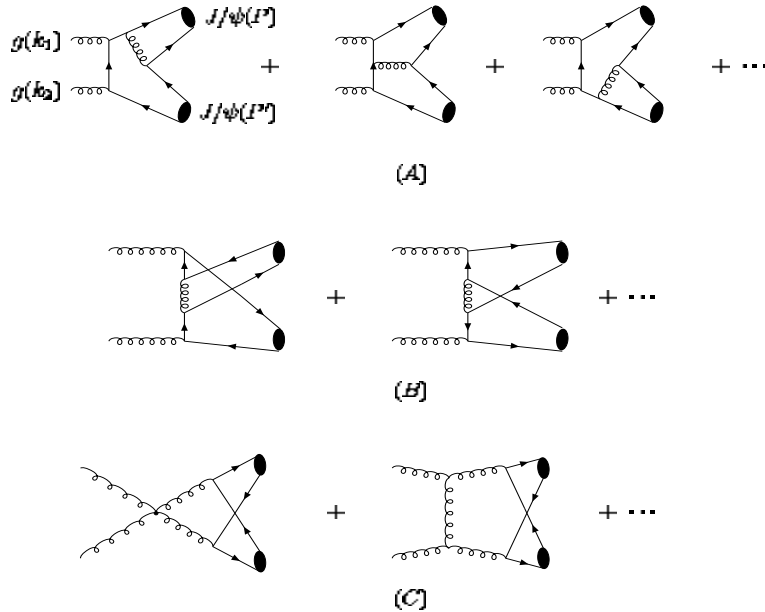


FIG. 2: Typical Feynman diagrams of  $J/\psi$  pair production in  $pp$  collision at leading order in color-singlet scheme.

It is worth noting that the  $J/\psi$  pair hybrid production scheme, i.e., one  $J/\psi$  in a pair is produced through CS scheme but the other is via CO scheme, is neglected in the calculation since its contribution is comparatively very small.

### III. INSTALLATION AND IMPLEMENTATION

The generator is compressed in a file named `DJpsiFDC.taz` and users could download it from:

<http://cid-4fc4170d6530982b.office.live.com/browse.aspx/.Public>

Installation and implementation procedures are described respectively below.

#### A. Installation

The installation steps are given below and for convenience we assume that:

1. the current user account is `user`;
2. the current directory is `/home/user`;
3. it is assumed that the user use "`chsh`" ; if not , the user should execute "`chsh useraccount`" or "`ypchsh useraccount`" to change the shell class to cshell ;
4. User has installed CERN library and CERN library should be CERN2001.

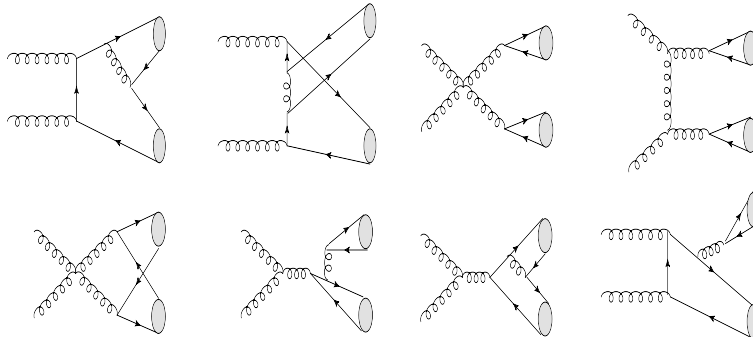


FIG. 3: Typical Feynman diagrams at leading order in color-octet scheme.

For the installation, user first need to decompress the downloaded gzip file by typing the following command.

```
"tar -xzf DJpsiFDC.taz"
```

then home directory "DJpsiFDC" is generated. Secondly, get into it by "cd DJpsiFDC" and set the correct path of CERN library in env.csh, then execute:

```
"source env.csh" and "installlib".
```

It will do the installation.

Note: users must firstly modify the path and cern library location in "env.csh" into their local paths, then execute "source env.csh" so as to establish the environment smoothly.

## B. Implementation

To implement the generator, user firstly needs to establish links to program library. After entered home directory of generator, user could execute "source env.csh" and "installlib" to realize it and this is a necessary procedure for the next operations. Then user must enter color-singlet part or color-octet part by executing "cd gg2jpsi/fort" or "cd octet\_gg2jpsi/fort". Take color-singlet part as the example.

After changed current directory to gg2jpsi/fort, execute program **make**, then three executable programs would appear. They are:

---

<b>int</b>	calculates and stores the cross-section in file <b>fresult.dat</b>
<b>gevent</b>	generates and stores parton-level events information in file <b>pdata1.dat</b>
<b>fdcpythia</b>	generates and stores the final events information in file <b>DJpsiFDC.lhe</b>

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Users only need to execute the executable programs to get generate events and get output files, but user must call **int** ahead to **fdcpythia**.

There are two input-files for users to change input parameters: **input.dat** and **parameter.input**. **input.dat** stores center-of-mass energy, and user could generate events under different collision energy by changing it. In **parameter.input**, user could configure initial parameters such as event number to generate, etc. The format of **parameter.input** is described as: each parameter occupies one line; in each line, the parameter name and value are separated by a equal sign (i.e. "=") like:

`parameter = value;`

the line which begins with a number sign (i.e. “#”) is recognized as the comment. All parameters used by DJpsiFDC in `parameter.input` are listed with brief explanation as:

**RUNNINGLEVEL(=1)** : To specify the running level. It needs not to be cared here.

**EVNTNUM** : To specify the number of the generated events.

**PARTONEVNTNUM** : The number of the generated parton-level events. It must be at least twice to EVNTNUM.

**PRESENTEVNTNUM** : The number of generated hadronic events in the last run. It is set automatically and should not be modified by users.

**RESET** : To control the program `fdcpythia` to run in two different modes – **Re-generation** mode and **Appending** mode. In DJpsiFDC package, we only use the **Re-generation** mode (**=1**), since all the generated events are erased, and new parton-level events and hadronic events are generated.

It should be noted that after changing collision energy in `input.dat`, user must re-execute `int` to calculate cross-section under new energy, or the generator would generate events under original collision energy.

The generator could also change transverse momentum and rapidity restrictions on the generated  $J/\psi$  pair. Users could execute “vi func.f”, and at line 166-176 of func.f, they could find the following codes:

```
a = dsqrt(p(3,3)**2+p(2,3)**2)
if(a.lt.4) out_of_physical_region = .true.
if(a.gt.40) out_of_physical_region = .true.
b = -dlog(tan(0.5*acos(dsqrt(p(3,3)**2
. +p(2,3)**2+p(4,3)**2)**(-1)*p(4,3))))
c = -dlog(tan(0.5*acos(dsqrt(p(3,4)**2
. +p(2,4)**2+p(4,4)**2)**(-1)*p(4,4))))
if(b.lt.-2.2) out_of_physical_region = .true.
if(b.gt.2.2) out_of_physical_region = .true.
if(c.lt.-2.2) out_of_physical_region = .true.
if(c.gt.2.2) out_of_physical_region = .true.
```

a is the transverse momentum, and b, c are pseudorapidity of respective  $J/\psi$ . Users could change the limitations by modifying the numbers after ".lt." or ".gt.". ".lt." means "less than", and ".gt." means "greater than". After changed limitations, users must re-execute ./make to re-compile, then operate as the above procedures.

#### IV. OUTPUT FORMAT

There are two output files for users: fresult.dat and DJpsiFDC.lhe. fresult.dat stores the calculated cross-section by the generator, and user could use this value to estimate the number of events in certain integrated luminosity.

DJpsiFDC.lhe is the primary output file storing main information of original and final particles. "LHE" means Les Houches Event, its content is identical with what was already defined by the Les Houches Accord in 2003[17]. This information is embedded in a minimal XML-style structure. Complete file format looks like

```
<LesHouchesEvents version="1.0">
<!--
# optional information in completely free format,
# except for the reserved endtag (see next line)
-->
<header>
<!-- individually designed XML tags, in fancy XML style -->
</header>
<init>
compulsory initialization information
# optional initialization information
</init>
<event>
compulsory event information
# optional event information
</event>
(further <event> ... </event> blocks, one for each event)
```

</LesHouchesEvents>

The LHE file has included all necessary information of original and final parton-level particles, such as beam energy, color label, particle ID, mom particle ID, four-momentum, invariant mass, etc.

## V. SUMMARY

We have presented a FORTRAN program package DJpsiFDC which is a generator for simulating  $J/\psi$  pair production. It has implemented primary leading-order  $2 \rightarrow 2$  processes and can generate events in color-singlet and color-octet mechanism respectively. The generator would create a LHE document containing initial and final particles information, which could be embedded into detector software systems. This package has been tested with setting the  $pp$  collisions energy at  $\sqrt{s}=10\text{TeV}$  and  $14\text{TeV}$ , and the collision energy could be changed. Monte Carlo simulation is being processed, and according to the actual LHC operation status, the case under  $7\text{TeV}$  is being studied. With data accumulation on LHC, the conclusions on this process could be attained in future two or three years.

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